PHOTOPRODUCTION OF ETAS AND N*(1535) ELECTROSTRONG PROPERTIES

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Abstract

From the new Mainz data of eta photoproduction off protons[1] and deuterons[2], we can extract, via the effective Lagrangian approach (ELA)[3], the electrostrong parameters ξ_p and ξ_n for the N*(1535) excitation. These parameters are, in units of $10^{-4} MeV^{-1}$, (2.20 ± 0.15) and (-1.86 ± 0.20) respectively. They yield the ratio of the helicity amplitudes for the excitation of N*(1535) by photons off neutrons and protons to be $A^n_{1/2}/A^p_{1/2} = -0.84 \pm 0.15$, a quantity of fundamental importance in the baryon structure. Best estimates in the quark model are close to this ratio.

1 Introduction

There has been a revival of the study of the electromagnetic excitation of the baryon resonances, thanks to the advent of the CW electron machines. Current generation of these machines have superior beam quality along with

high duty factor. This, together with good detector technology, has resulted in a vastly improved data base in the first and second resonance regions of the nucleon spectrum. On the theoretical side, the interesting tests of QCD involve the Q^2 evolution of the helicity amplitudes, where Q^2 is the negative of the virtual photon mass squared. The real photon point of this evolution curve anchors the non-pertubative domain, which continues till Q^2 is sufficiently large to have the perturbative QCD (PQCD) rules set in.

The reaction of interest in this paper is the photoproduction of the eta meson off nucleons:

$$\gamma + p \rightarrow \eta + p, \tag{1}$$

$$\gamma + n \rightarrow \eta + n, \tag{2}$$

with thresholds $E_\gamma = 707.2 MeV$ and $706.9 MeV$ respectively, where E_γ is the lab photon energy. A large number of recent papers have looked at these reactions both experimentally[1, 2] and theoretically[3, 4, 5, 6, 7]. A particular interest in this reaction is to study the nucleon to N*(1535) helicity amplitude that dominates this[3] class of reactions. On the experimental side, very high quality experiments have been done at Mainz[1, 2], while less accurate investigations at Bates[8] and Bonn[9] have also added to our knowledge in this region. Although the theoretical investigations have been principally in the context of quark models, sophistications have been introduced in the framework of these models[10] making a meaningful comparison between theory and experiment possible.

A particular interest from the theoretical point of view is the extraction of the amplitudes $A^p_{1/2}$ and $A^n_{1/2}$ for the p and n targets respectively to excite the N*(1535) resonance. Granted that we have to deal with model dependence in this extraction from the data, it is of value to see how far this model dependencce can be reduced.

In our analysis, we construct the photoproduction amplitude by using the ELA[3], which has been very successful in the first[11], second[3] and third[12] resonance regions. The main contributions[3] to the amplitude are the nucleon Born term, vector meson exchanges and the excitation of the nucleon resonances, dominated in this case by the N*(1535) resonance. In contrast to the pion photoproduction, where the pion-nucleon channel couples to a large number of s-channel resonances, the eta-nucleon channel has strong selectivity of the N*(1535) intermediate state.

2 The E_{0+} amplitude

The dominant amplitude in the N*(1535) excitation region is the E_{0+} amplitude. In Table 1, we show the real part of the E_{0+} amplitude at the threshold of the eta photoproduction, as obtained from our ELA fits to the various sets of data. Notice the large difference between the E_{0+} amplitude as obtained from our fits to the old data base[13] and the results inferred from our fits to the photoproduction data obtained at Mainz, from the proton[1] and the neutron[2] targets, by Krusche *et al.*. The latter are not direct measurements, but inferences from the photoproduction off deuteron targets[2]. Notice the sign difference between E^p_{0+} and E^n_{0+}, and the dominance of the N*(1535) in both of these amplitudes. This is the basis for our extraction of the electrostrong properties of the N*(1535) excitation off nucleons.

3 The differential eta photoproduction cross-section

In Fig.1 we present a sampling of the angular distributions, as obtained by Krusche *et al.* for the proton target and the angular distributions for the neutron target as inferred from their data off the deuteron target. Fig.1, upper pannel, shows our fit to the proton data for parameters $\alpha = 1.0$, $\beta = 0.88$, $\delta = 2.05$ for the N*(1520) sector[3] and the parameter $\Lambda^2 = 1.2GeV^2$ for the vector meson sector[3]. Fig.1, lower pannel, incorporates the prediction of the Capstick quark model[10] at the same α, β, δ and Λ. The quality of fit does not change appreciably when these parameters are varied. The flatness of the angular distribution at low energy is a direct reflection of the dominance of the E_{0+} amplitude, which, in turn, is dominated by the N*(1535) excitation. The quality of these comparisons is consistently excellent.

4 The extraction of the electrostrong amplitude parameter for the N*(1535) excitation

As Benmerrouche and Mukhopadhyay[3] first showed, one can reduce the model dependence of the ELA in fitting the data by introduction of the

Table 1: A comparison of various contributions to the E_{0^+} multipole, in units of $10^{-3}/m_{\pi+}$, for the $\gamma + p \rightarrow \eta + p$ and the $\gamma + n \rightarrow \eta + n$ reactions, at their respective thresholds. The parameters, defined in [3], $\alpha = 1$ and $\Lambda^2 = 1.2 GeV^2$ are used. The targets are indicated. Our model parameters are fitted to the experiment of Krusche *et al.*[1] for protons, and our inferred angular distributions for neutrons[2].

	Old data base	Mainz Data	
	p	p	n
Nucleon Born terms	-6.05	-3.4	2.3
$\rho + \omega$	2.89	2.9	-2.0
$N^*(1440)$	-0.47	$--$	$--$
$N^*(1535)$	12.06	12.2	-10.5
$N^*(1520)$	1.46	1.6	-0.2
$N^*(1650)$	-0.94	$--$	$--$
$N^*(1710)$	0.25	$--$	$--$
Total	9.21	13.3	-10.4

parameter

$$\xi_i = \sqrt{\chi_i \Gamma_\eta} A^i_{1/2} / \Gamma_T \tag{3}$$

where χ_i is a kinemetic factor, Γ_η and Γ_T are the eta-nucleon and total widths of the N*(1535) decay, $A^i_{1/2}$ is the electromagnetic helicity amplitude in the target i ($i = p$ or n) to excite N*(1535) resonance.

In Table 2, we present three different fits in our ELA to the Mainz proton data to establish the following fact: *while the extraction of the $A^p_{1/2}$ is model-dependent and is strongly dependent on the choice of Γ_η and Γ_T, the parameter ξ_p is not.* We can repeat this excercise[3] and show the same to be true for the neutron target. Thus, from the recent Mainz data, our ELA fits yield the following parameters, which are largely insensitive to the model uncertainties of our ELA, also confirmed by similar numbers obtained in a simple Breit-Wigner fit of the N*(1535) excitation of the E_{0^+} multipoles, inferred from the experiment[3]. We get

$$\xi_p = (2.20 \pm 0.15) \times 10^{-4} MeV^{-1}, \tag{4}$$

$$\xi_n = (-1.86 \pm 0.20) \times 10^{-4} MeV^{-1}, \tag{5}$$

yielding the ratio

$$A^n_{1/2} / A^p_{1/2} = -0.84 \pm 0.15. \tag{6}$$

Notice that *all strong interaction effects have dropped out in extracting the last ratio.* Thus, this is a quantity particularly suitable for a direct comparison with the hadron models.

5 Concluding remarks

We do not have yet any "measurement" of this ratio or the estimates of the parameters ξ_i in the lattice QCD approach, but that would be very timely, and welcome. In the meantime, we can compare the amplitudes ξ_i and $A^n_{1/2}/A^p_{1/2}$ with the available quark model results[10]. These results are qualitatively (and some cases quantitatively) in agreement with our extracted value, but more precision is needed in the fomer to compare with the precision we can get out of the data.

Polarization observables are going to be very helpful in futher tests of our extracted parameters. New facilities like the Mainz microtron(MAMI),

Table 2: Fitted $A^p_{1/2}$ and inferred ξ_p for N*(1535) obtained from the new MAMI data[1], along with χ^2 per degree of freedom, for various analyses. Three rows are fits to the differential cross sections,with different values of strong eta-nucleon widths and resonance parameters. a and b have N*(1535) amplitude only while c consists of the ELA amplitude as described in the text.

	$A_{1/2}$	ξ	χ^2/df
a	113	2.2	2.8
b	144	2.3	3.0
c	98	2.2	1.4

Grenoble light source (GRAAL) and the Continuous Electron Beam Accelarator Facility (CEBAF) will help these developments in the near future.

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References

[1] B. Krusche *et al.*, *Phys. Rev. Lett.* **74**, 3736 (1995); **75**, 3032 (1995).

[2] B. Krusche *et al.*, *Phys. Lett.* **B**, in press; priv. comm. (July 1995).

[3] M. Benmerrouche and N. C. Mukhopadhyay, *Phys. Rev. Lett.* **67**, 1070 (1991). M. Benmerrouche, N. C. Mukhopadhyay and J.-F. Zhang, *Phys. Rev.* **D51**, 3237 (1995). N. C. Mukhopadhyay, J. -F. Zhang and M. Benmerrouche, *Phys. Rev. Lett.*, **75** 3022 (1995) and *Phys. Lett.* **B**, in press.

[4] L. Tiator, C. Bennhold and S. S. Kamalov, *Nucl. Phys.* **A580**, 455 (1994).

[5] C. Sauermann, B. L. Friman and W. Nörenberg, contribution to the Meson-Nucleon 1995 Symposium, Blaubeuren, Germany, p. 148 (1995), A. Švarc *et al.*, contribution to the Meson-Nucleon 1995 Symposium, Blaubeuren, Germany, p. 99 (1995).

[6] N. Keiser, P. Siegel and W. Weise, *Munich preprint* (1995).

[7] M. Batinić, I. Šlaus, A. Švarc and B.M.K. Nefkens, *Phys. Rev.* **C52**, 2188 (1995).

[8] S. Dytman *et al.*, *Phys. Rev.* **C51**, 2170 (1995).

[9] J. Price *et al.*, *Phys. Rev.* **C51**, R2283 (1995).

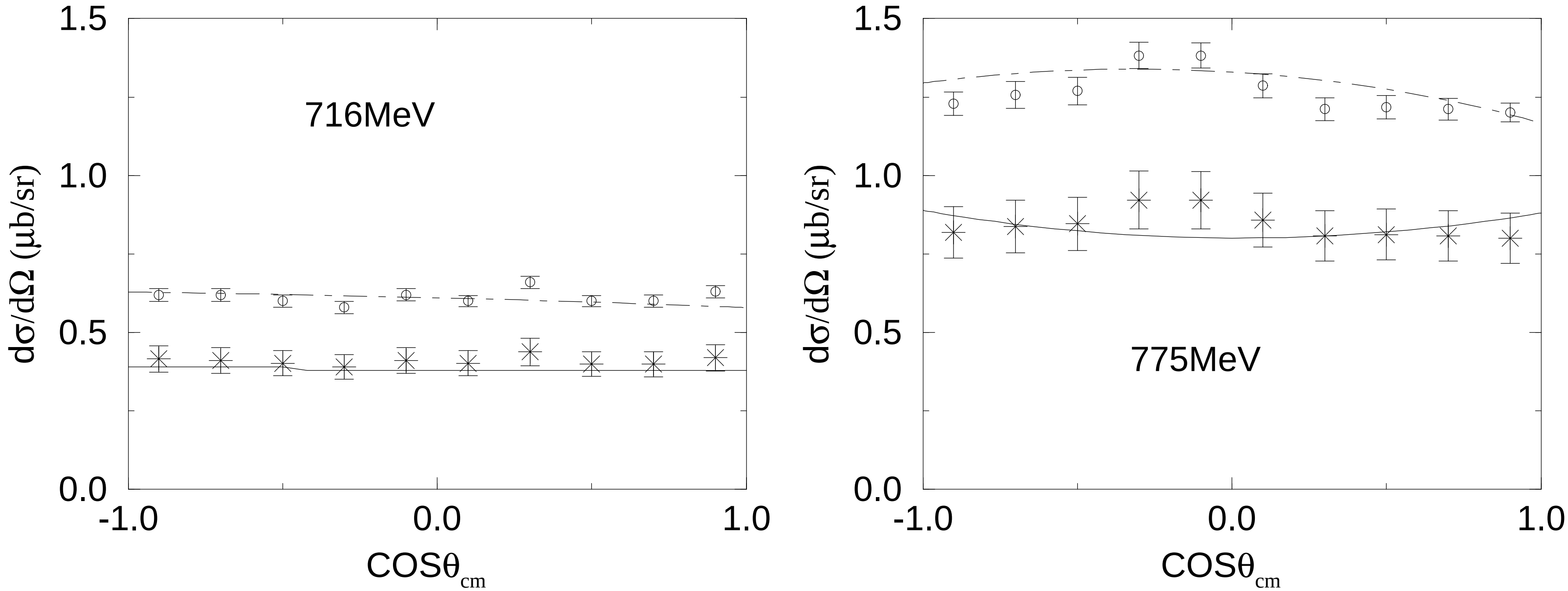
[10] R. Koniuk and N. Isgur, *Phys. Rev.* **D21** 1868, (1980). S. Godfrey and N. Isgur, *Phys. Rev.* **D32**, 189 (1985). I. G. Aznauryan and A.S. Bagdesaryan, *Yad. Fiz.* **41**, 249 (1985) [*Sov. J. Nucl. Phys.* **41**, 158 (1985)]. Z. Li and F. E. Close, *Phys. Rev.* **D42**, 2207, (1990). S. Capstick, *Phys. Rev.* **D46**, 2864 (1992). S. Capstick and W. Roberts, *Phys. Rev.* **D49**, 4570 (1994). S. Capstick and B.D. Keister, *Phys. Rev.* **D51**, 3598 (1995). Z. Li, CMU preprint, nucl-th/9506033 (1995).

[11] R. M. Davidson, N. C. Mukhopadhyay and R. S. Wittman, *Phys. Rev.* **D43**, 71 (1991).

[12] J. -F. Zhang, N. C. Mukhopadhyay and M. Benmerrouche, *Phys. Rev.* **C52**, 1134 (1995).

[13] H. Genzel, P. Joos, and W. Pfeil, in *Landolt-Börnstein,* New Series I/8 (Springer, New York, 1973), 278. R. Baldini *et al.*, in *Landolt-Börnstein,* New Series I/12b (Springer, New York, 1988), 361. S. Homma *et al.*, *J. Phys. Soc. Jpn.* **57**, 828 (1988) and the references there in.

Fig. 1: The upper pannel: the angular distributions for eta photoproduction off protons for two sample values of E_γ, 716 and 775 MeV. Experimental points (circles) are from [1], and the dot-dashed lines are our effective Lagrangian fits. The lower pannel: our predictions for the neutron target from quark model using $A^n_{1/2}/A^p_{1/2} = -0.83$ (solid line), vs. the inferred differential cross-section (stars)[2].



1.5
1.0
0.5
0.0
716MeV
dσ/dΩ (μb/sr)
-1.0
0.0
1.0
COSθ$_{cm}$
1.5
1.0
0.5
0.0
775MeV
dσ/dΩ (μb/sr)
-1.0
0.0
1.0
COSθ$_{cm}$